

HEMISPHERIC DISTRIBUTION OF 5-DAY MEAN 700-MB. CIRCULATION CENTERS

JAMES F. O'CONNOR

Extended Forecast Branch, U.S. Weather Bureau, Washington, D.C.

ABSTRACT

The hemispheric distributions of all significant 5-day mean High and Low centers at 700 mb. observed twice weekly during the years 1947-58 are presented by months and latitudes and also for the entire 12-yr. period. Average seasonal circulations and their relative vorticities for the same period, as well as zonal geostrophic winds, are shown for comparison. Although the relative vorticity patterns of the long-period circulation resemble the patterns of occurrence of 5-day circulation centers, there are some centers which are not easily related to features of the circulation on such a long time scale as 12 years.

1. INTRODUCTION

Extended weather forecasts are currently prepared in the U.S. Weather Bureau within the framework of a predicted mean circulation at 700 mb. In this prediction the question often arises as to the likelihood of a 5-day mean Low or High center occurring in a certain region at a particular time of the year. A documentation of past occurrences therefore constitutes a useful synoptic climatology for the extended-range forecaster as well as for others concerned with the general circulation and development of better methods for its prediction. The most recently published compilation of this kind was concerned with the frequencies of mean troughs and ridges on 5-day and 30-day mean 700-mb. charts [1].

It is known that circulation features have a greater preference for some regions than others. Some of these regional preferences are so pronounced that they are clearly evident in the long-period averages of the circulation, as centers of action. However, other preferential regions were not so well manifested in the "normal" 700-mb. patterns published in 1952 [2]. A more recent set of circulation averages for the 12 years from 1947 to 1958 [3] compares more favorably with the centers to be presented here since it applies to the same period of record. Highs and Lows are summarized separately by months as well as for the entire 12-yr. period. Mean circulation and vorticity charts for each season as well as for the entire 12-yr. period, not heretofore published, are also presented for convenience.

A comparison of the occurrences presented here with those previously published for daily surface centers [4] reveals large differences as well as many similarities. The differences largely reflect changes with height due to thermal structure. However, some may be caused by the earlier and longer sample used in [4]. As an example of the differences due to elevation: surface Highs have a

greater frequency in winter in the Great Basin of the western United States than in any other area of similar size. At 700 mb., however, mean Highs in winter are almost non-existent there. Instead, the upper-level support for surface Highs in the Basin is found in the high frequency of mean ridges there, as suggested in [1].

Obviously the relatively short period of sample presented here may not reflect precisely the occurrences at some other period due to secular variations.

2. REPRESENTATION OF DATA

The charts from which these data were extracted were twice-weekly 5-day-mean 700-mb. maps on file at the Extended Forecast Branch, with data at standard intersections of latitude and longitude in the shape of a diamond [2, 3]. 1947 was judged to be the earliest year for which reasonably complete hemispheric coverage of upper-air data was available. Even so, the frequencies in southern Asia are not exactly comparable with those in the remainder of the hemisphere. Because of incomplete analyses there from 1947 to 1950, the totals in Asia at 30°-40° N. are about one-sixth less, and at 20°-30° N. about one-third less, than comparable totals elsewhere. 1958 was the last year used so that the data would be comparable to the 12-yr. circulation averages in [3].

The basic data were obtained by superimposing a transparency successively on each 5-day mean 700-mb. map. Dots were placed at the centers of those closed contours which had a height difference of at least 20 ft. from all surrounding grid points. No maxima or minima were recorded on the equatorward edge of the map unless suggested by partial closure of a contour. When a new center coincided with a previous one on the transparency, its dot was displaced enough so that both could be distinguished on the monthly composites. This shift is justifiable since the precise location of a center

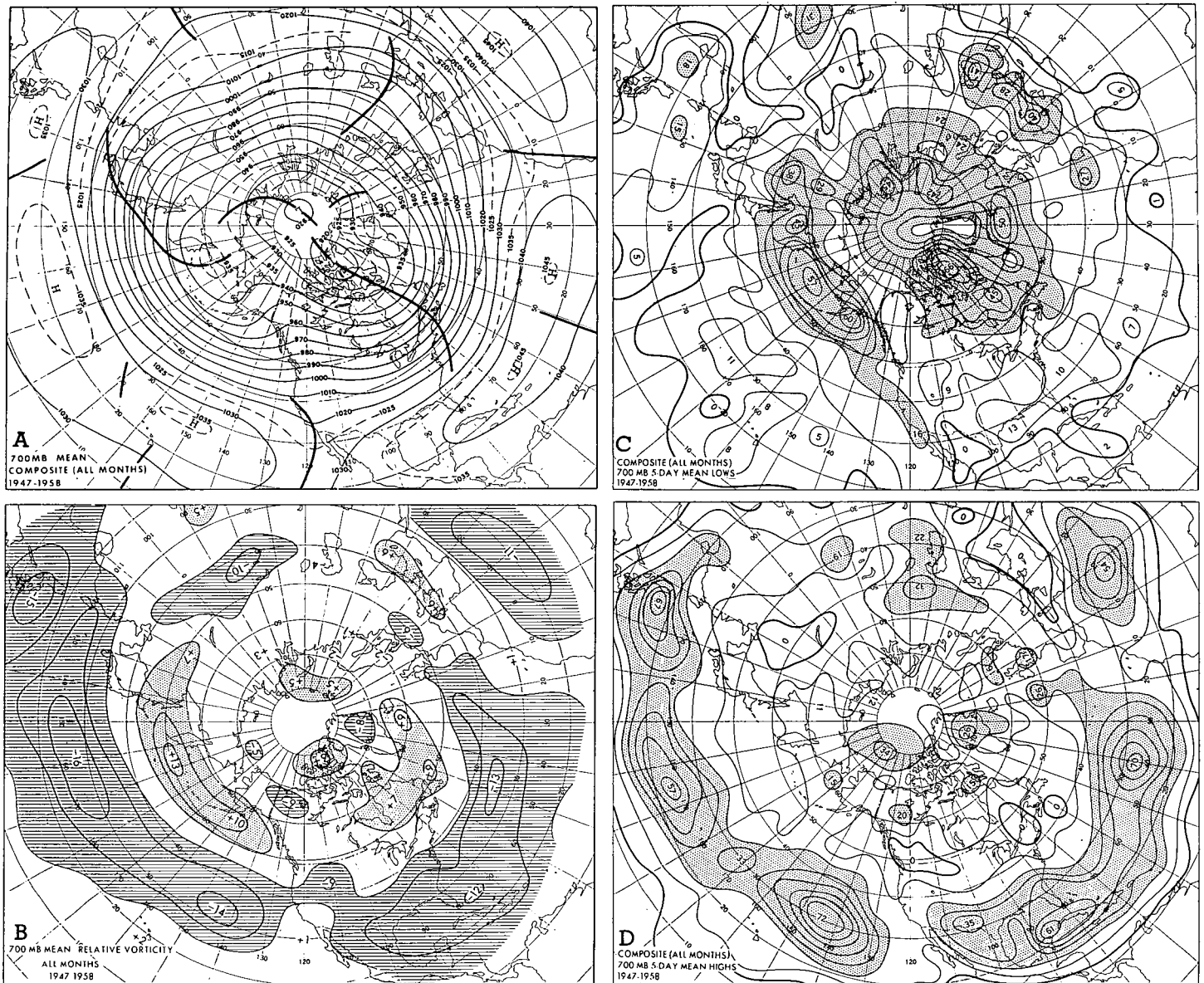


FIGURE 1.—(A) Average 700-mb. circulation for all months from 1947 to 1958. Contours (thin solid and dashed lines) are labeled in tens of feet, and troughs (minimum latitudes of contours) are shown in heavy solid lines. (B) Vertical component of geostrophic relative vorticity of chart A, drawn at intervals of $4.0 \times 10^{-6} \text{ sec.}^{-1}$ with zero line omitted and maxima labeled in units of $10^{-6} \text{ sec.}^{-1}$ (C) Frequency of all 5-day-mean Low centers at 700 mb. from 1947 to 1958 per unit area, with thin isolines at odd multiples of five, zero line heavy, over 15 centers stippled, and maximum number of centers indicated per unit area. (D) Same as (C) for High centers.

is usually debatable in view of the coarseness of the grid. The uncertainty is usually greater in the case of Highs (which have weaker gradients near the center) than of Lows.

For the entire 12-yr. summary of all months (fig. 1), equal-area totals were computed, utilizing a grid (5° square at the equator, approximately 90,000 n. mi.²) suggested in [5]. A simple analysis of these totals was possible because of the large number of centers, about 7,000 Lows and 7,300 Highs. Maximum occurrences per unit area were labeled at the appropriate locations. These should not be confused with totals within an isopleth.

The summaries of individual months contained too few centers (about 600 around the hemisphere) to justify an analysis of equal-area totals since they varied with the type of grid used, the orientation, and the mesh size. It was therefore decided that the distribution of centers was most usefully portrayed by the dots themselves since the sample was not so large that the dots obscured one another.

3. SOME HIGHLIGHTS OF THE REGIONAL DISTRIBUTION OF LOWS

A comparison of all 5-day mean Low centers at 700 mb. (hereafter often referred to simply as "Lows") observed

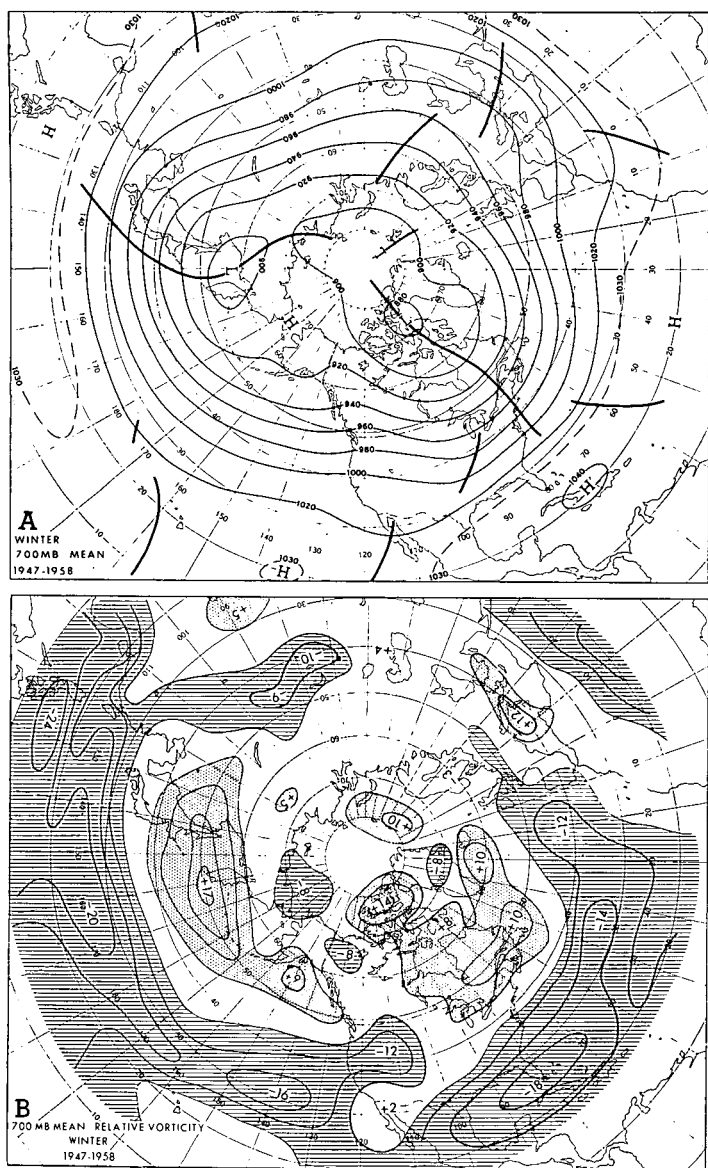


FIGURE 2—(A) Mean winter (Dec.-Feb.) circulation at 700 mb. (1947-58 average) (see legend fig. 1A). (B) Relative vorticity of chart A (see legend, fig. 1B).

from 1947 to 1958 (fig. 1C) with the corresponding long-period circulation and its relative vorticity (fig. 1A, B) shows that at higher latitudes Lows occur with the greatest frequency in regions dominated by the cyclonic centers of action, while at lower latitudes they are favored in regions of vorticity maxima associated with mean troughs in the circulation. The maxima of Lows in figure 1C represent, of course, composites of the various seasonal preferences reviewed below.

WINTER LOWS

The greatest regional frequency of winter Lows occurs near Kamchatka, reflecting the strongest vorticity in the normal circulation at 700 mb. (fig. 2). The largest concentration of centers, per unit area, however, is found

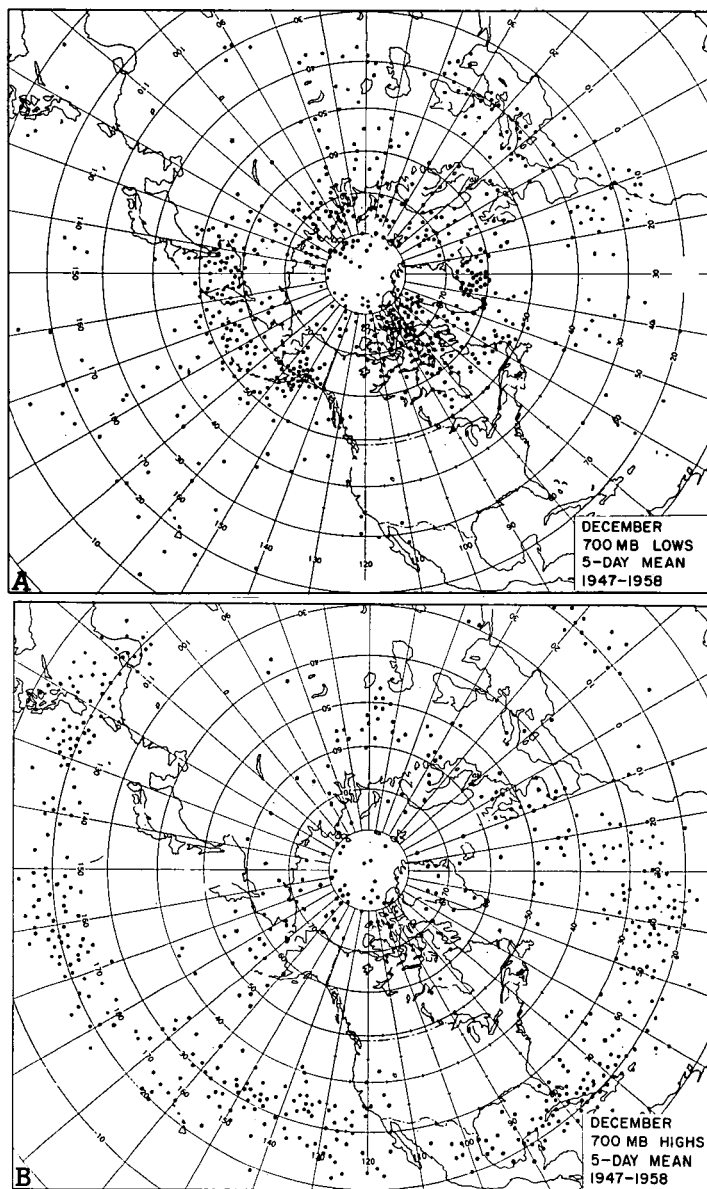


FIGURE 3—December locations of observed 5-day-mean circulation centers at 700 mb., 1947-58, for (A) Lows and (B) Highs. Each dot represents one center.

near Kodiak, Alaska, in December (fig. 3A), with Baffin Island a close second, both in regions of normal vorticity maxima.

At middle and lower latitudes, 5-day Lows are frequent in the central Pacific, notably north of Hawaii in January (fig. 4A) and south of Hawaii in February (fig. 5A), reflecting the frequency of the "cutoff" process associated with blocking farther north.

In the Atlantic, 5-day-mean Lows occur along a zone near 40°N . with a frequency that is surprising in the eastern part in view of the strong anticyclonic vorticity of the average winter circulation there (fig. 2B). Noteworthy in February is the southward shift of mean Lows to near southeastern Canada and a reduction in frequency

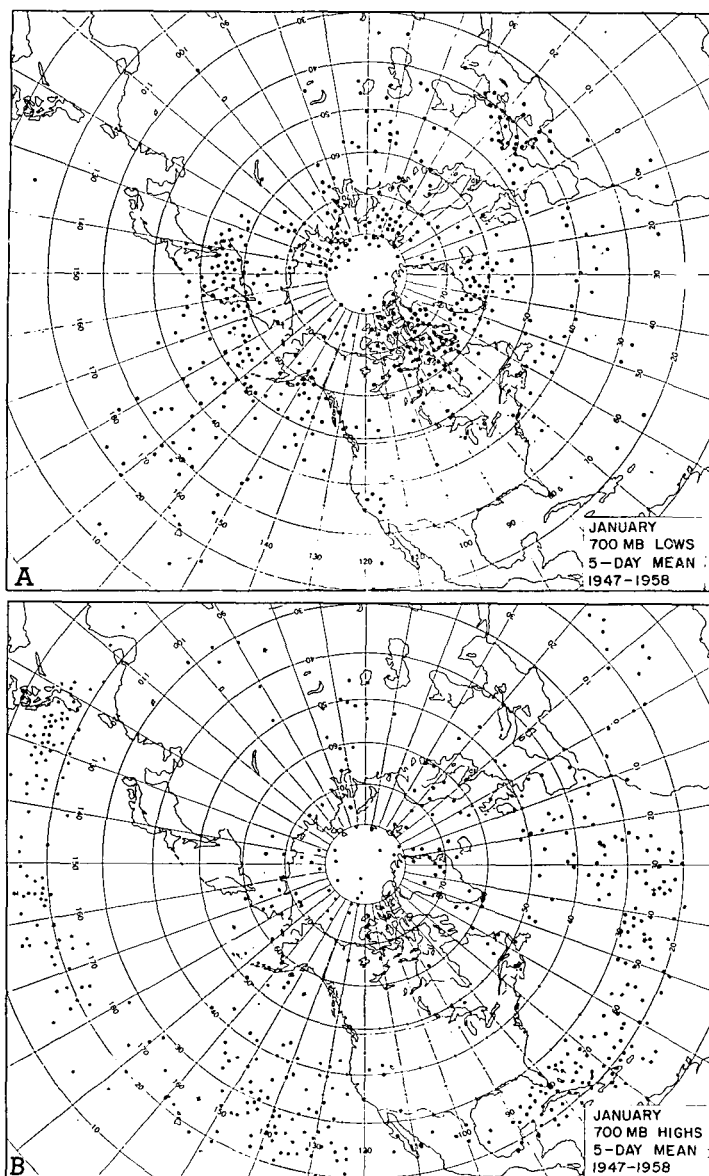


FIGURE 4.—January centers (see legend, fig. 3).

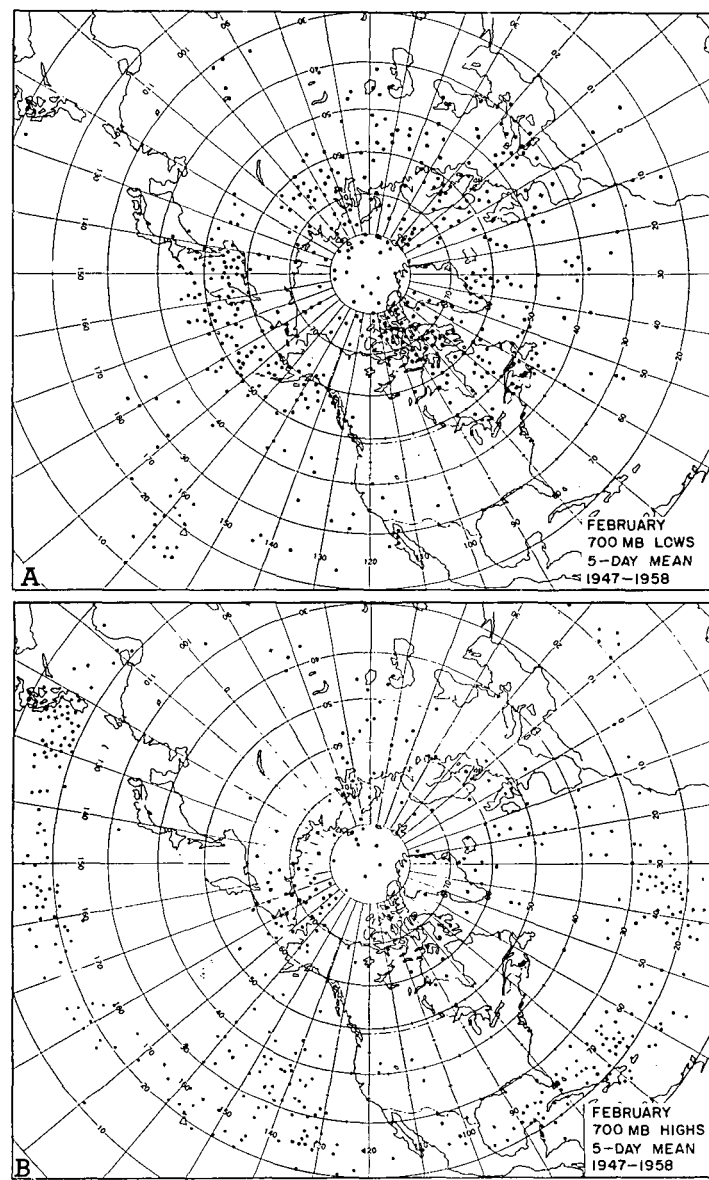


FIGURE 5.—February centers (see legend, fig. 3).

near the January vorticity maximum in the Denmark Strait, events probably linked to the annual index cycle [6].

Outside the upper latitudes, the most favored region for 5-day Lows in winter is along the northern Mediterranean coast, where a strong vorticity maximum exists in the winter circulation. These Lows reveal the frequent cutting off of the southern end of the European trough from the centers of action in the Norwegian and Barents Seas.

SPRING LOWS

During spring, 5-day Lows at 700 mb. are again highly favored in the Bering Sea and Gulf of Alaska and an extensive vorticity maximum is centered in the western Aleutians, the strongest in the hemisphere (fig. 6B). In the spring, Lows increase sharply, compared with winter,

in the eastern Pacific, especially in March (fig. 7A) when a weaker ridge appears in the average circulation.

In the central United States mean Lows are most frequent in spring, particularly in April (fig. 8A) and May (fig. 9A), not only at 700 mb. but also at sea level [4], probably contributing to the increased tempo of severe local storms at this time. Near Newfoundland, an intense vorticity maximum occurs in spring, second only to that in the western Aleutians (fig. 6B). This is evidenced by a southward shift of 5-day Lows from February to March as a result of increased blocking farther north.

In Europe a westward shift of 5-day Lows is noteworthy in spring from two favored winter locations near Italy and eastern Russia to the western Mediterranean and western Russia, particularly from March to April. By May Lows are

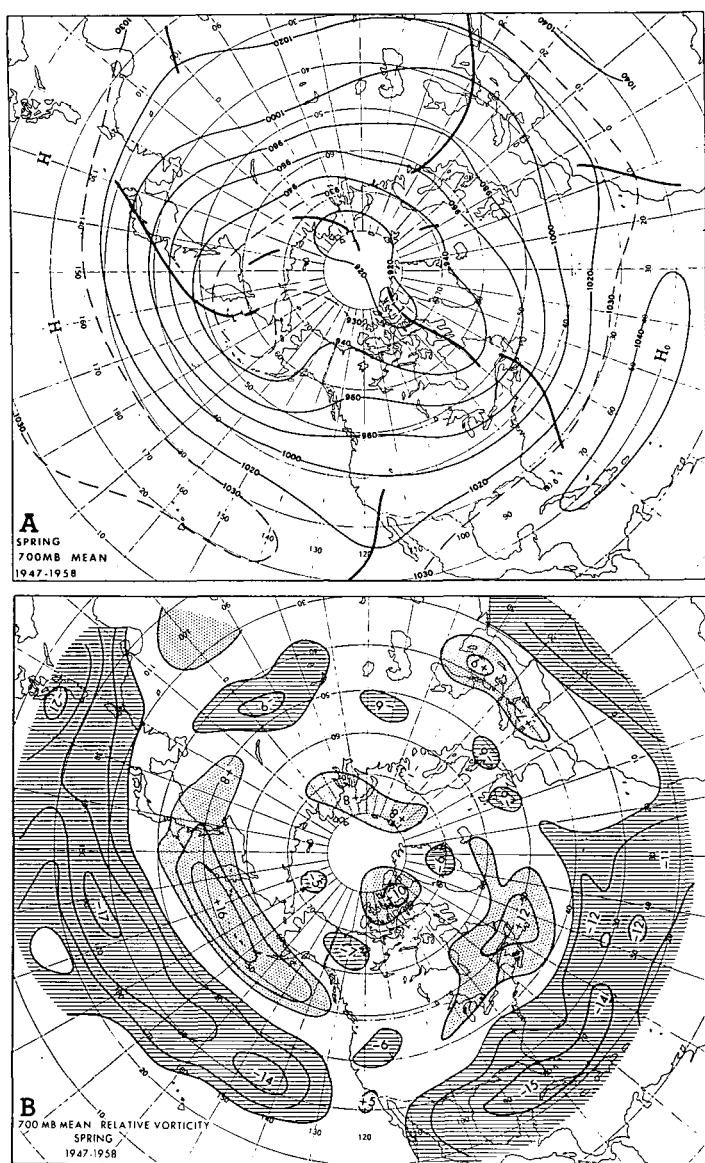


FIGURE 6.—Spring (Mar.-May) circulation and relative vorticity (see legend, fig. 2).

strongly preferred westward from the United Kingdom, accompanying a resurgence of blocking to the north.

SUMMER LOWS

Summer Lows are more numerous than those of spring north of 50°N., especially in June (fig. 11A), over most of the hemisphere except in western North America and Greenland. There summer vorticity minima (fig. 10) are even stronger than in previous seasons. Near the United Kingdom 5-day Lows occur with sharply increased frequency in summer, the only season that the normal circulation there is cyclonic.

At lower latitudes summer Lows increase noticeably over earlier frequencies in northeastern India and near the southeastern coasts of Asia and North America especially in August (fig. 13A). In the eastern oceans

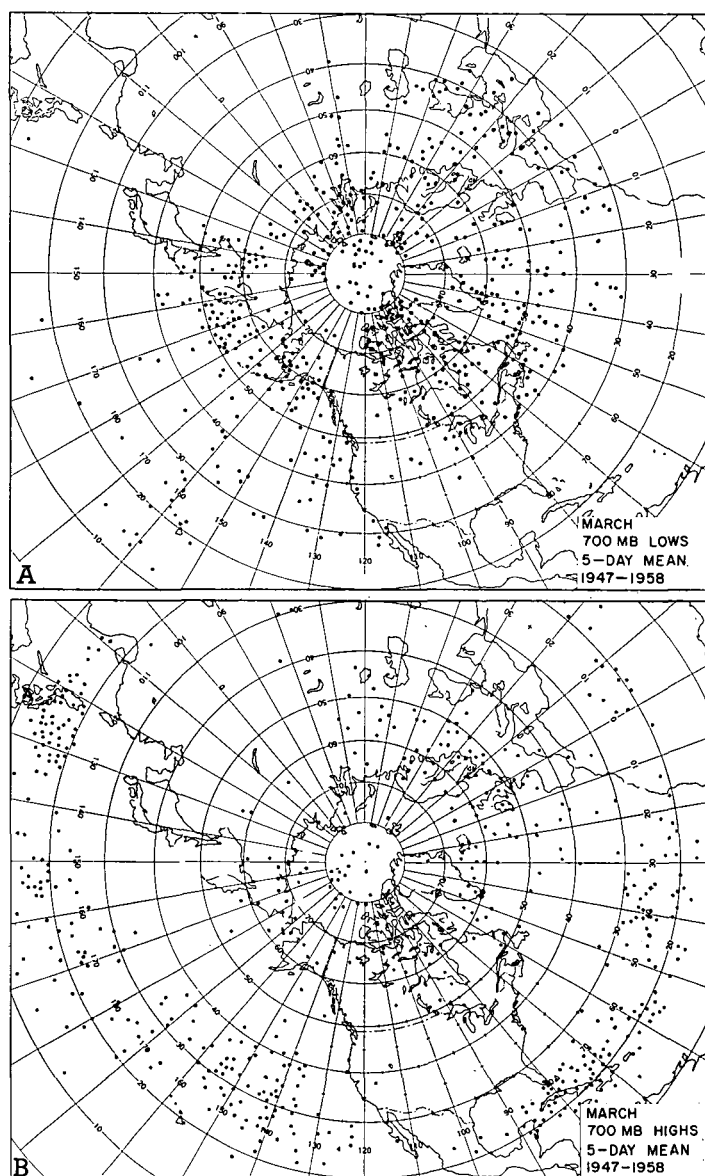


FIGURE 7.—March centers (see legend, fig. 3).

and western land areas, summer Lows decrease from frequent events in June to mostly scattered ones in July and August, accompanying the seasonal growth of the subtropical Highs.

AUTUMN LOWS

During autumn the greatest vorticity maximum in the hemisphere is found near Kodiak Island affiliated with the deepest trough of the year in the central Pacific (fig. 14). Five-day Low centers increase correspondingly in that region, notably in September (fig. 15A).

In the United States the trough usually found off the east coast in other seasons retrogrades to the Mississippi Valley in the fall accompanied by more frequent 5-day Lows in the southeastern United States and adjacent Atlantic. This area averages about 25 percent more

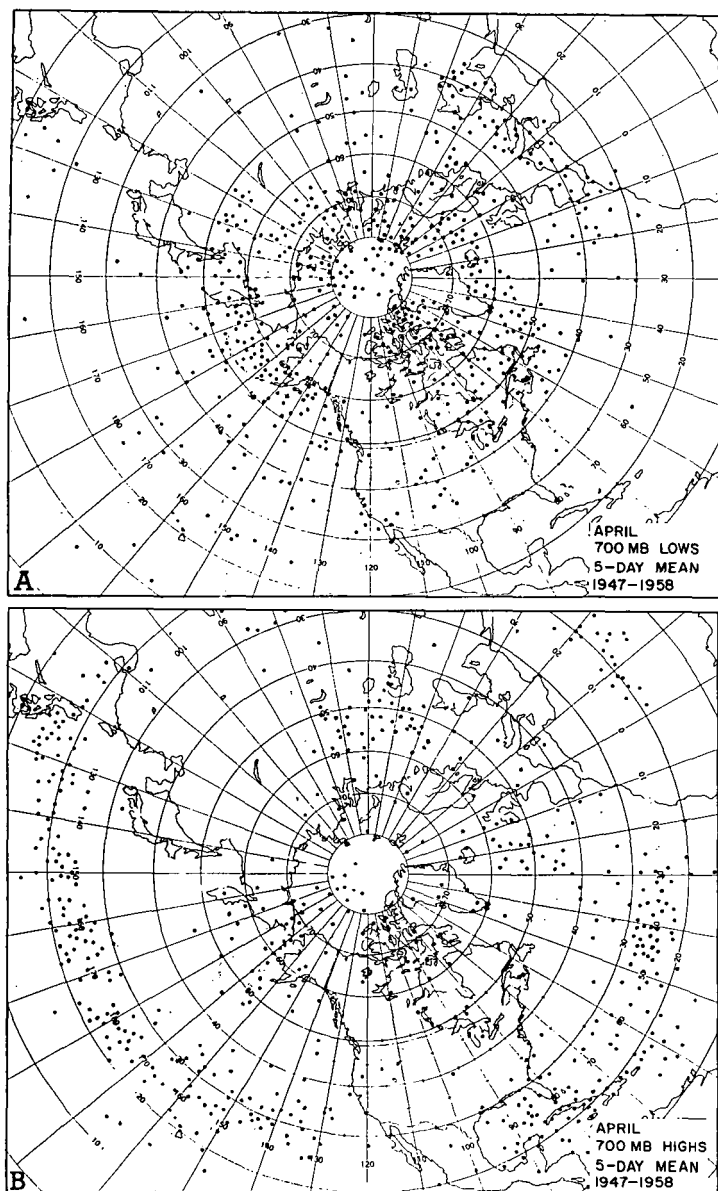


FIGURE 8.—April centers (see legend, fig. 3).

tropical centers at 700 mb. in September than in August, in contrast with a decreasing trend near southeastern Asia.

During October (fig. 16A) 700-mb. Lows proliferate in the Mediterranean, accompanying trough development in the average circulation [3], while practically disappearing over a large area of the Atlantic west of Europe. By November (fig. 17A) low-latitude centers almost disappear in the regions of high frequency of previous months except near the Philippines, while at high latitudes 5-day centers are found to a large extent in proximity to the vorticity maxima in the average circulation.

4. SOME HIGHLIGHTS OF THE REGIONAL DISTRIBUTION OF HIGHS

The most favored regions for 5-day mean Highs at 700 mb. (hereafter often referred to simply as "Highs")

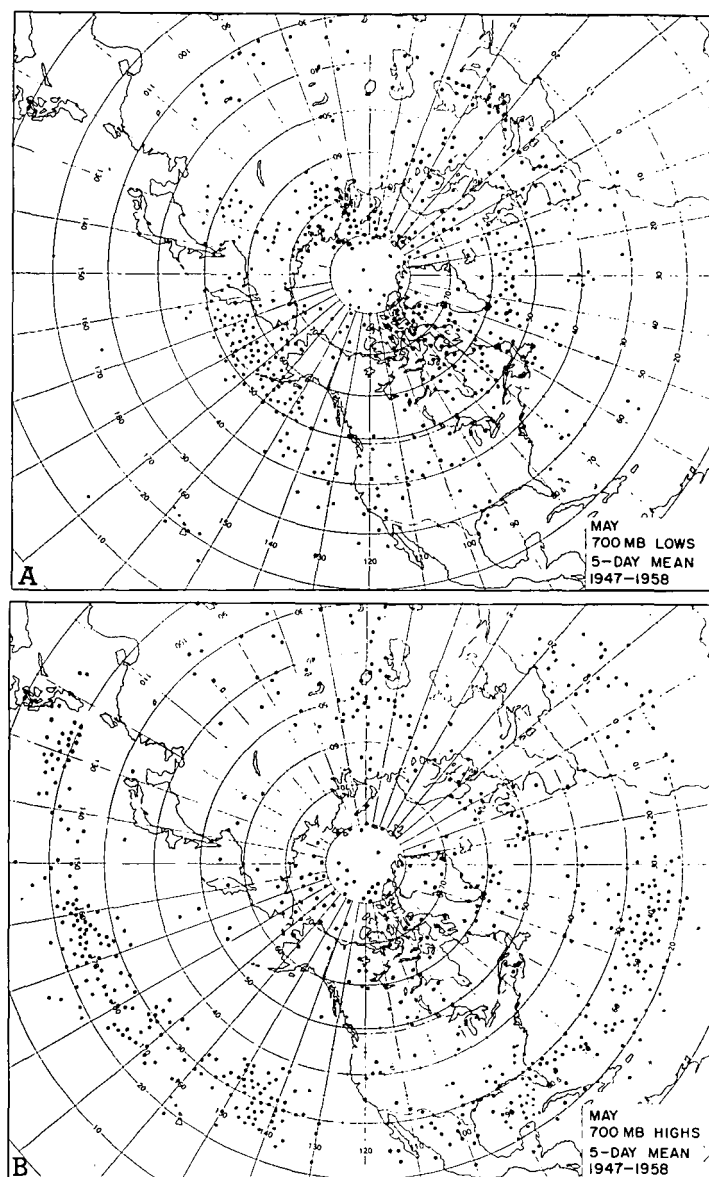


FIGURE 9.—May centers (see legend, fig. 3).

are evident in figure 1D, which reflects all centers observed during the 12 years, 1947-58. The greatest frequencies of Highs are associated with the various cells of the subtropical anticyclones (fig. 1A) and their vorticity minima (fig. 1B). At high latitudes aggregates of blocking 5-day High centers are associated with vorticity minima, often in the vicinity of ridges in the average circulation. The maxima in figure 1D are, of course, composites of the various seasonal preferences.

WINTER HIGHS

At low latitudes, 5-day winter Highs are most heavily concentrated in the western parts of the oceans, where the normal circulation cells and vorticity minima are strongest, notably near the Philippines and Cuba (fig. 2). In the eastern Atlantic 5-day Highs occur over a wide range of latitude particularly in December (fig. 3B) and

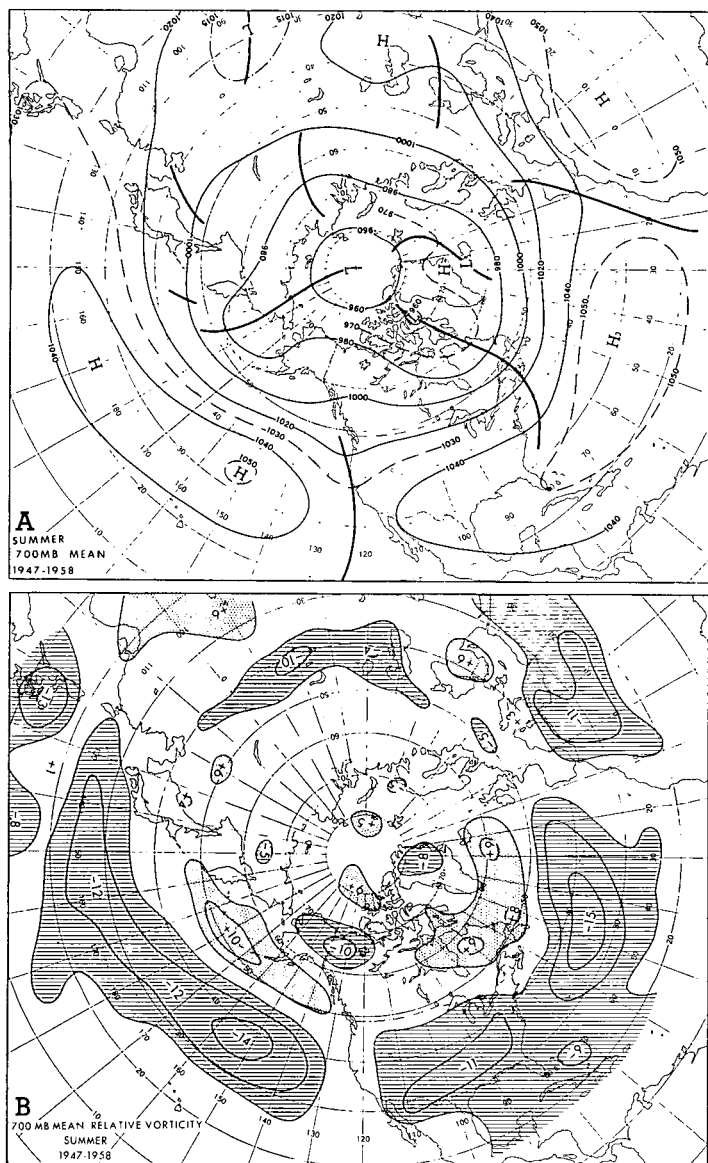


FIGURE 10.—Summer (June–Aug.) circulation and relative vorticity (see legend, fig. 2).

January (fig. 4B), associated with a strong ridge in the winter circulation. This is in sharp contrast to the relative absence of 5-day Highs at 700 mb. in the western United States, where the vorticity of the seasonal ridge is of comparable magnitude. Nevertheless surface Highs occur with great frequency in the Great Basin in winter as shown by the appearance of a High in the long-period average circulation [3]. At low latitudes relatively few winter Highs occur at 700 mb. over land masses, presumably because the relative coolness is unfavorable for their maintenance.

At high latitudes there is a strong preference for blocking Highs near the Bering Strait in winter, and especially in February (fig. 5B), to such an extent that a High cell appears in the normal circulation for that region. The sharp decrease in 5-day High centers farther east ap-

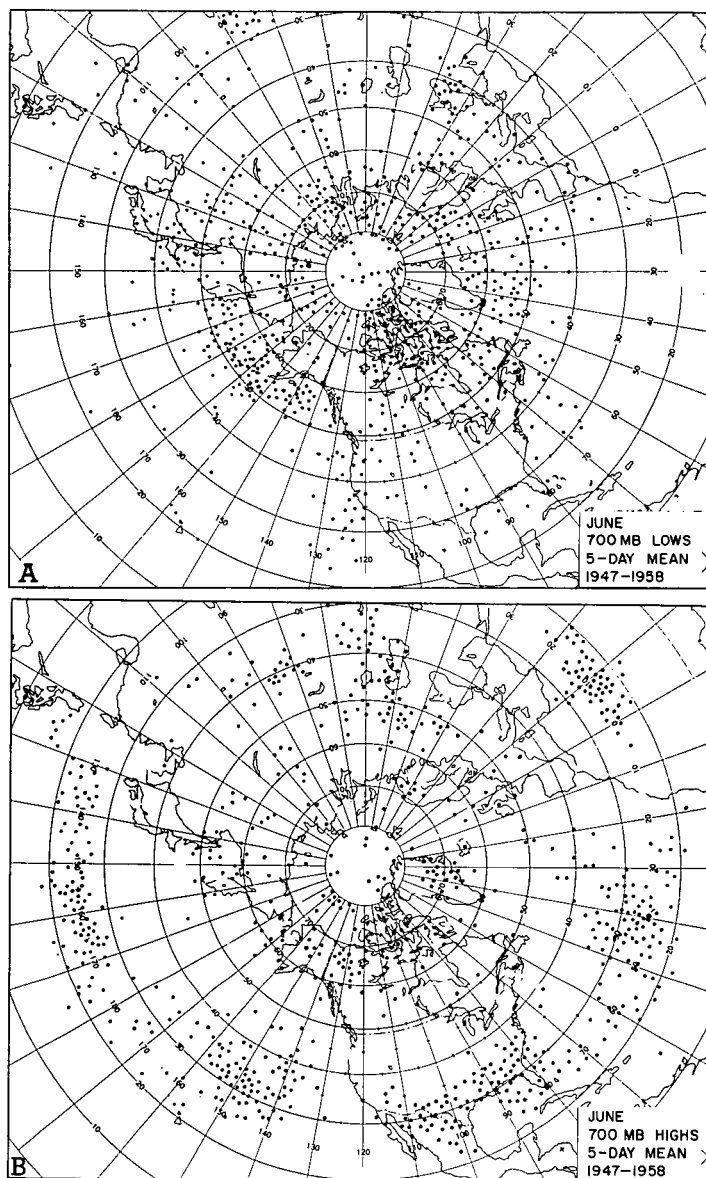


FIGURE 11.—June centers (see legend, fig. 3).

parently reflects a tendency for the Bering Sea ridge to drive cold air southward across high mountains and over relatively warm waters in the Gulf of Alaska. This results in the creation of cyclonic vorticity there [7]. Another region favorable for 700-mb. Highs is in the Soviet Union northeastward from the Caspian Sea, but surprisingly far to the west of the Asiatic ridge and its vorticity minimum and even farther west of the persistent Siberian surface High near Lake Baikal (see [3]).

SPRING HIGHS

During spring, the central oceanic High centers are more frequent than in winter, especially in April (fig. 8B) and May (fig. 9B), resulting in a more equal distribution among the various anticyclonic cells and their vorticity minima in the average circulation (fig. 6).

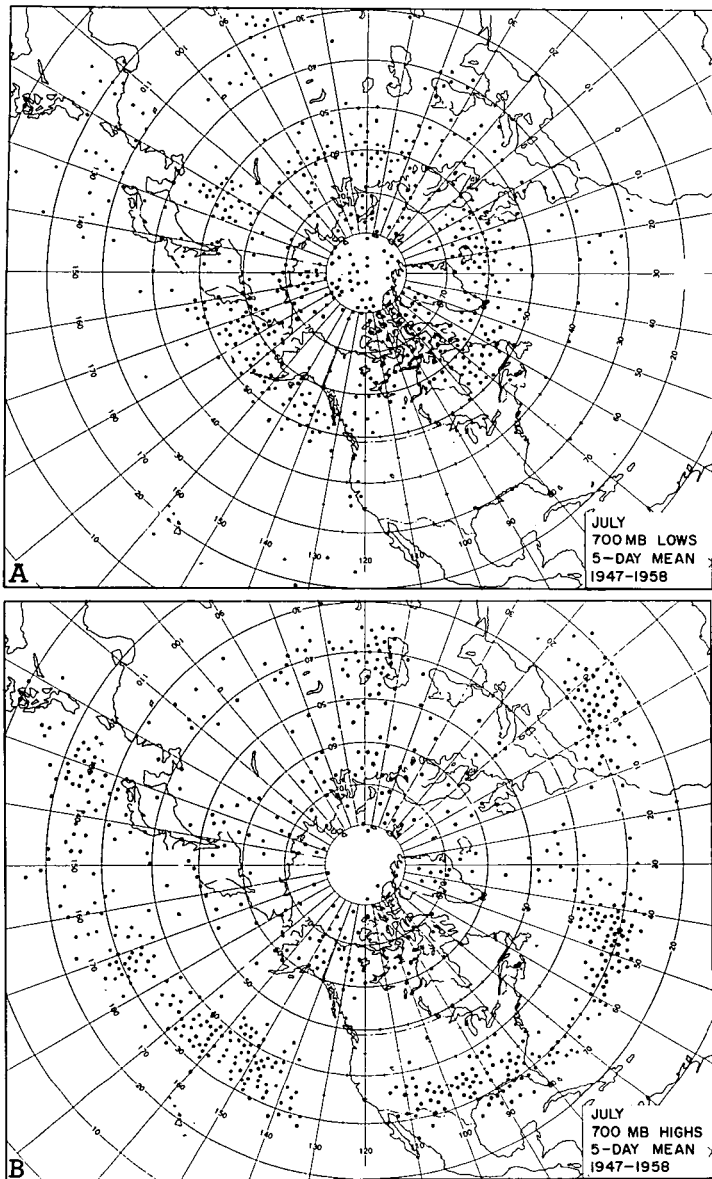


FIGURE 12.—July centers (see legend, fig. 3).

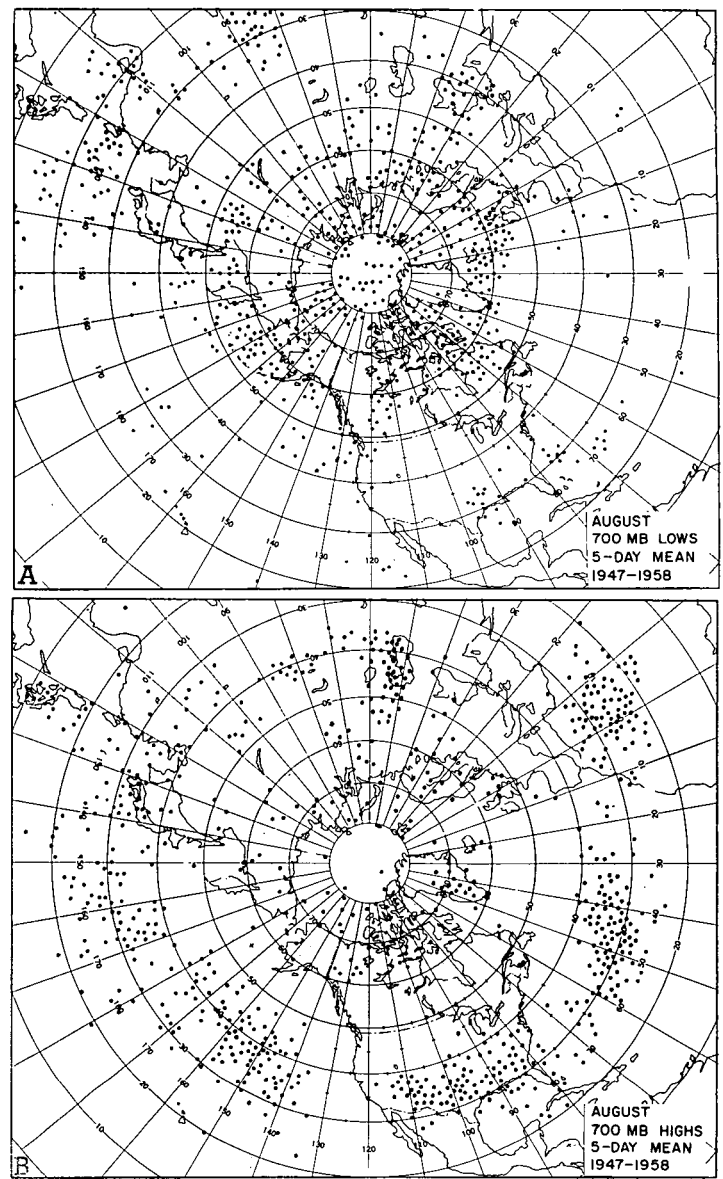


FIGURE 13.—August centers (see legend, fig. 3).

In the Atlantic, as there are fewer Highs at middle latitudes than in winter, a more distinct separation is apparent in spring between the subtropical centers and the blocks of the north Atlantic, eastern Canada, and Europe. The latter increase noticeably in March (fig. 7B) associated with increased negative vorticity in the seasonal circulation compared with previous months.

By April, 5-day Highs begin to migrate northward toward the southeastern United States and westward across the Gulf of Mexico, while during May the annual northward shift of subtropical centers is well underway in the Atlantic and the United States.

SUMMER HIGHS

The strongest concentration of subtropical High centers during the year is observed in summer, notably in the

eastern Pacific, central Atlantic, the southern United States, and North Africa, especially in July (fig. 12B) and August (fig. 13B), in agreement with the strongest and northernmost seasonal anticyclones during the year (fig. 10). The northernmost migration of subtropical centers occurs north of Hawaii in August, with some as far north as 49°N ., whereas in the United States and the Atlantic a sharp northern limit occurs at 40°N .

The proliferation of 700-mb. Highs over the southern United States in summer represents not only a northward shift of spring centers from the Caribbean, but also a 50 percent increase in frequency. They average about one center every 5-day period over the United States and adjacent waters. This persistence is comparable to that observed in North Africa. Throughout the hemisphere as a whole, summer Highs are about 18 percent more fre-

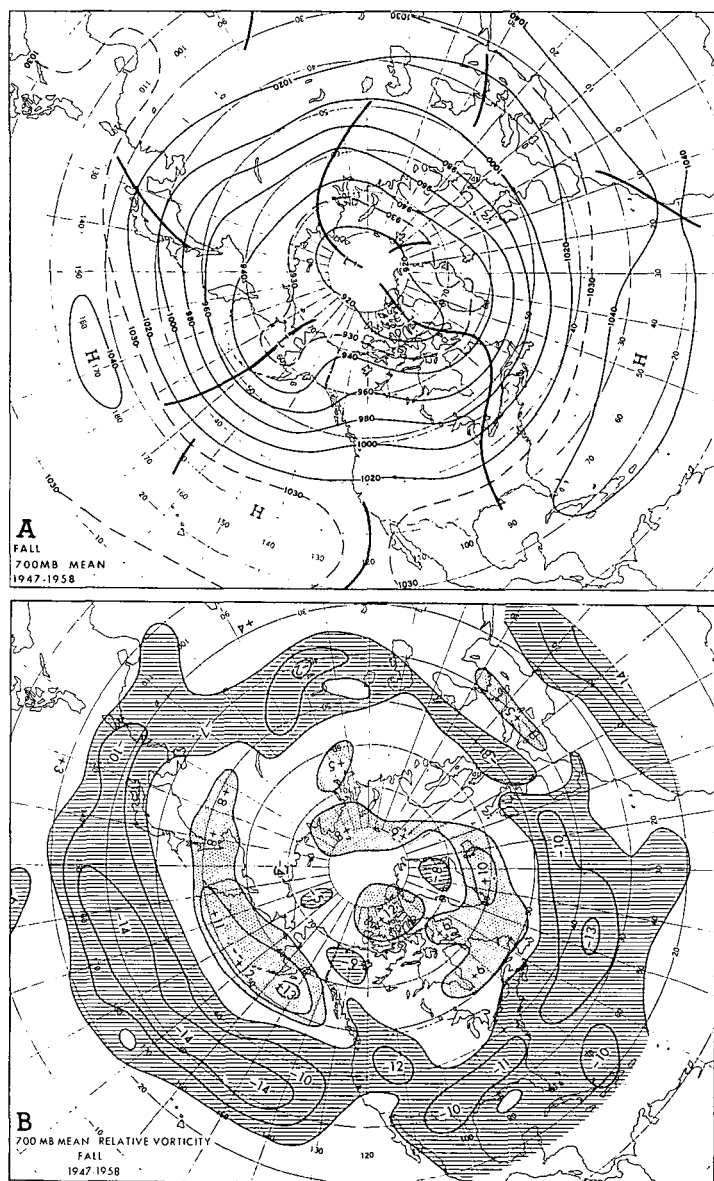


FIGURE 14.—Autumn (Sept.-Nov.) circulation and relative vorticity (see legend, fig. 2).

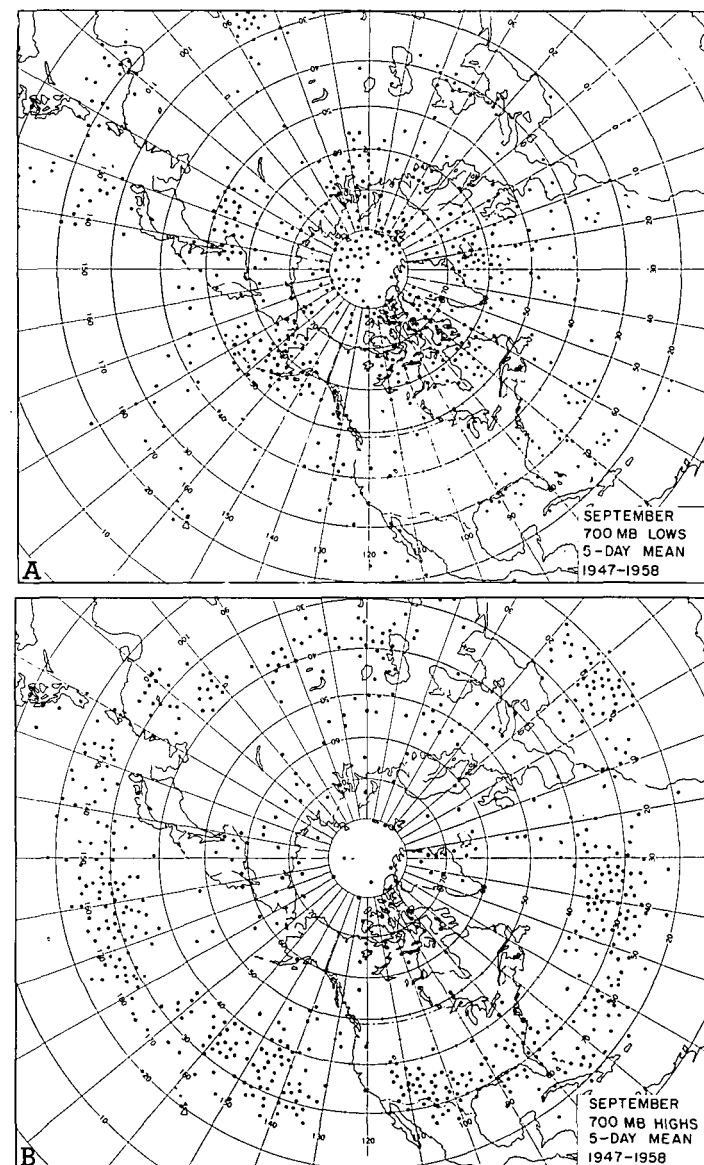


FIGURE 15.—September centers (see legend, fig. 3).

quent than those of spring and about 30 percent more frequent than winter Highs.

Over Asia also, from the Caspian Sea eastward to Japan, summer Highs are more frequent than those of any other season in connection with a zonal ridge in the average circulation near 40°N .

At high latitudes summer Highs are most frequent over land, notably near the Yukon and Greenland, especially in June (fig. 11B). Blocks also occur to a lesser extent over the Barents Sea and are considerably less frequent than in spring over the North Atlantic and eastern Canada.

AUTUMN HIGHS

Mean Highs are fewer in autumn at subtropical lati-

tudes, in the preferred regions of summer. However they are more favored in the eastern oceans and western land areas of the United States and Europe, in agreement with the increased anticyclonic vorticity of the autumn circulation there (fig. 14). The southward migration of subtropical Highs begins in September (fig. 15B) and continues throughout the autumn.

At high latitudes a sharp reduction in frequency of blocking Highs occurs, especially in the Yukon, Greenland, and the Barents Sea in September. They all but disappear at high latitudes in October (fig. 16B) except north of the Bering Sea where they are more frequent than in previous months, and become even more frequent in November (fig. 17B).

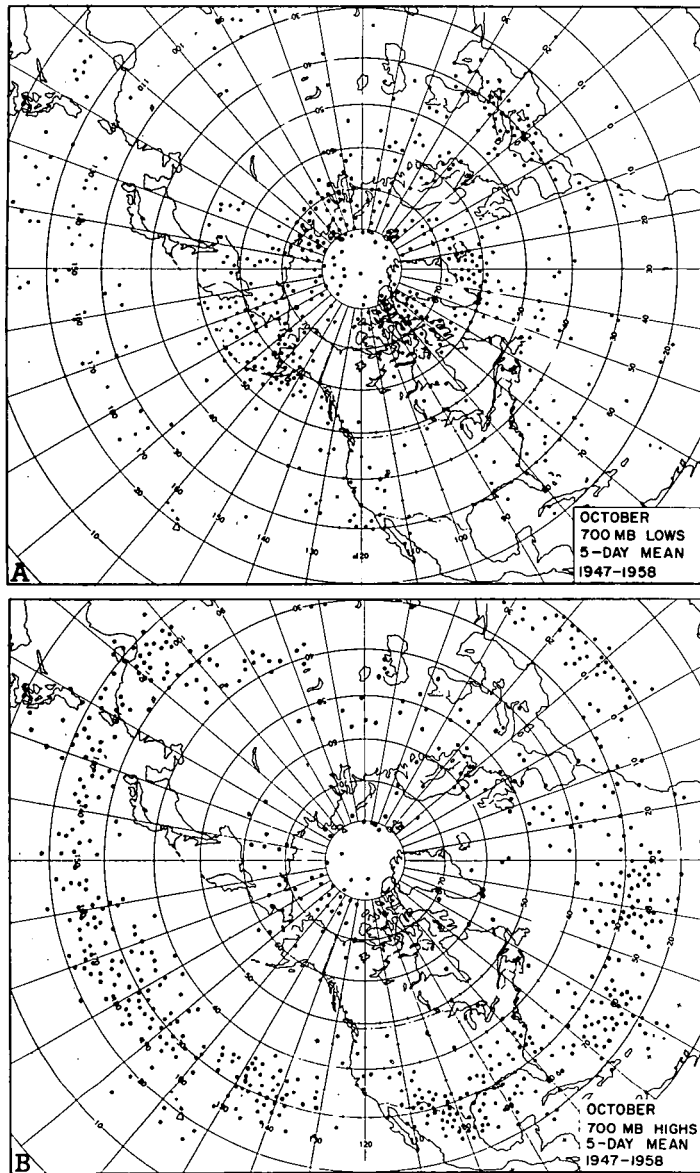


FIGURE 16.—October centers (see legend, fig. 3).

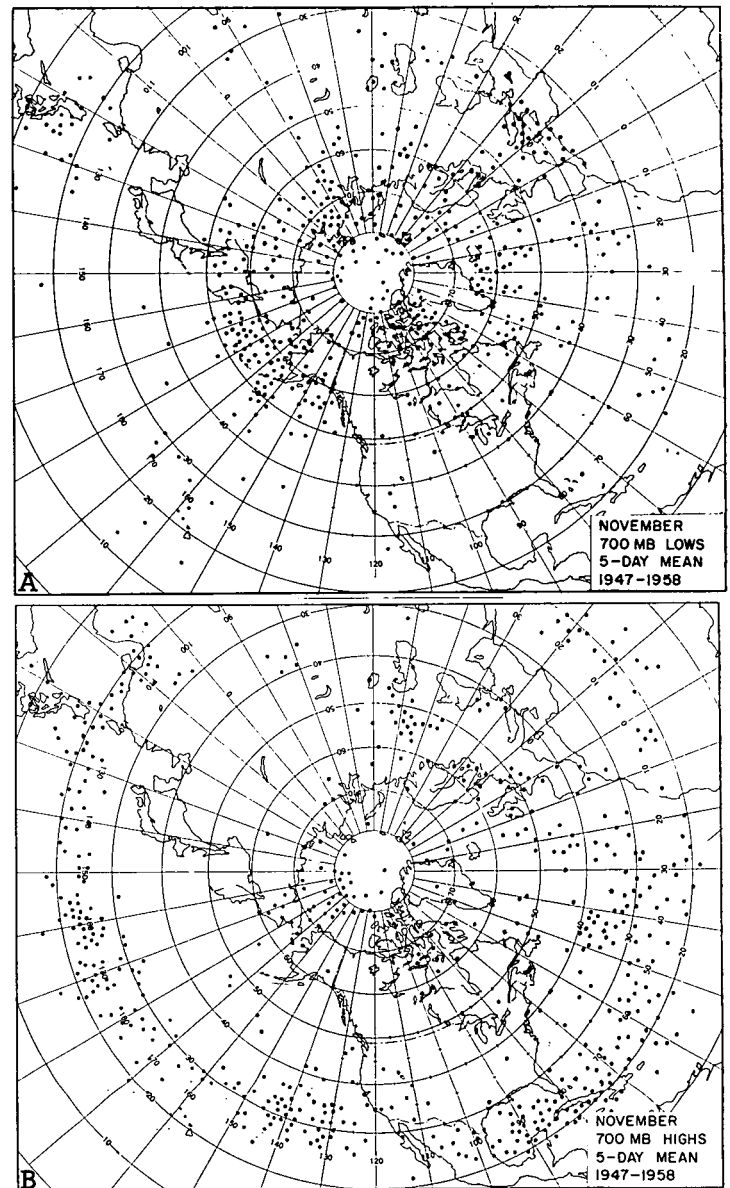


FIGURE 17.—November centers (see legend, fig. 3).

5. VARIATION WITH LATITUDE

LOWS

For all months combined (fig. 18) mean Lows at 700 mb. are most frequent between 55° and 60° N. About 75 percent of all Lows occur north of 45° N. and about 50 percent between 50° and 70° N. North and south of 60° N. there is a rapid decrease in frequency with no latitudes of secondary maxima in the all-month totals.

A seasonal breakdown of latitudinal variations (fig. 19) shows definite secondary maxima of Lows at lower latitudes (25° – 30° N.) in both summer and fall, with summer most marked. At high latitudes the greatest frequencies of the year also occur in summer (at 55° – 60° N.), with the smallest frequency maximum in fall. Another

secondary frequency maximum at very high latitudes (75° – 80° N.) is weakly suggested in all seasons except winter.

A monthly stratification of the latitudinal variations (fig. 20A) shows that although the greatest frequencies occur at 55° – 60° N. in most individual months, they occur somewhat farther south (50° – 55° N.) in May and June and farther north (60° – 65° N.) in October. There appear to be secondary latitudes of maximum frequency in many of the non-winter months, notably at 75° – 80° N. in July, August, and September, and at 25° – 30° N. from June to October. At low latitudes the greatest frequencies occur in August and September.

In general the pattern of monthly variations of latitudinal totals shown in figure 20A is similar to that found

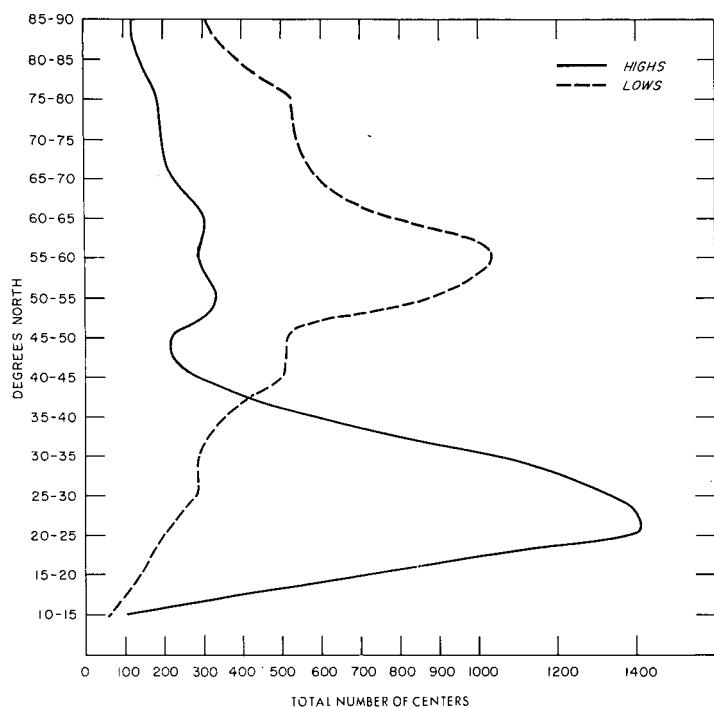


FIGURE 18.—Latitudinal profiles of locations of all 5-day-mean Lows (dashed) and Highs (solid) at 700 mb. observed from 1947 to 1958, totaled by 5° latitude bands.

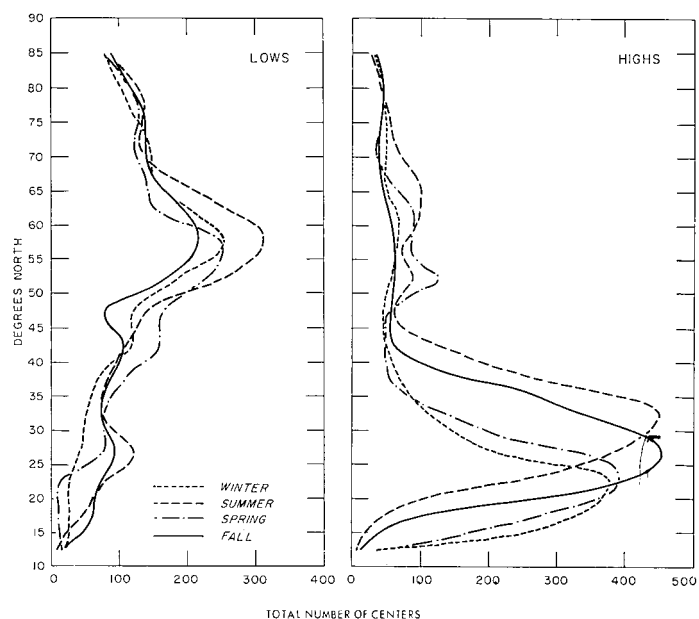
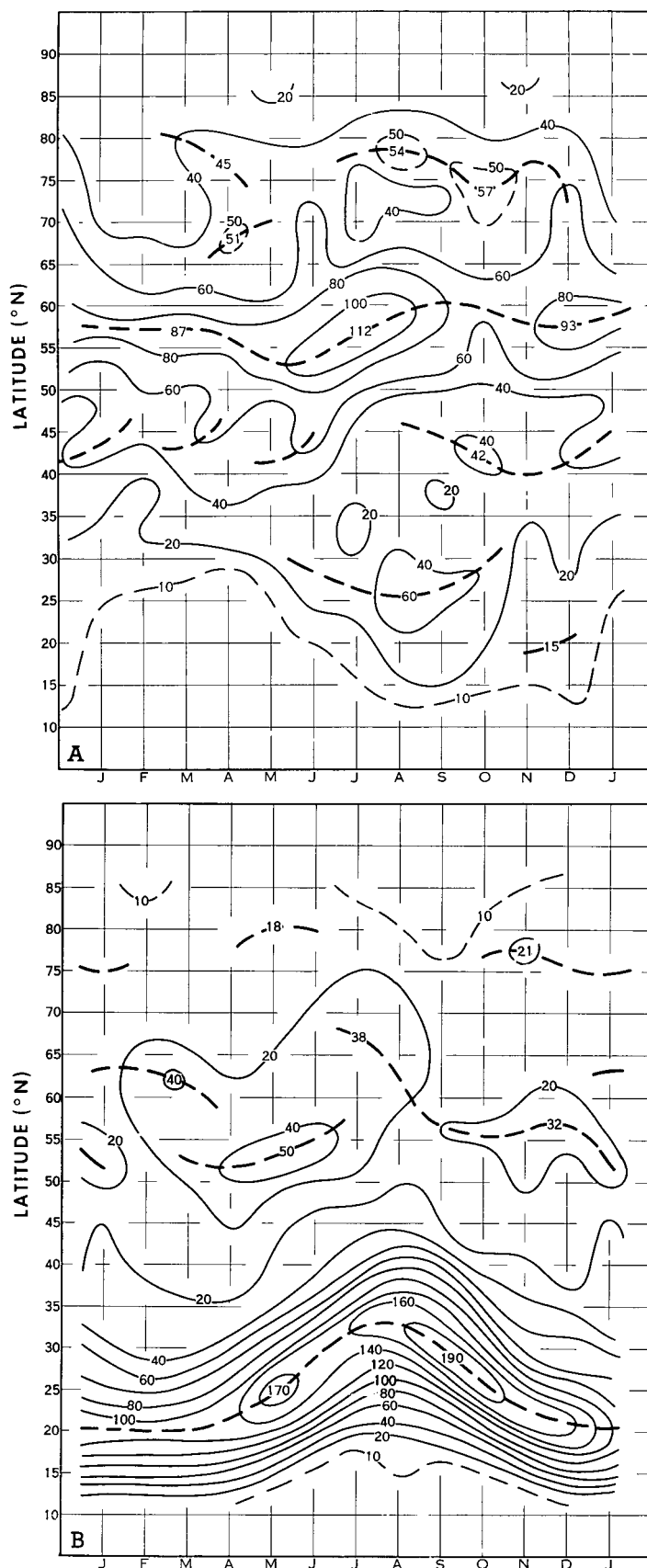


FIGURE 19.—Latitudinal profiles of locations of 5-day-mean Lows (left) and Highs (right), by seasons, at 700 mb. from 1947 to 1958, totaled by 5° latitude bands. Key to seasonal curves given in chart on left.



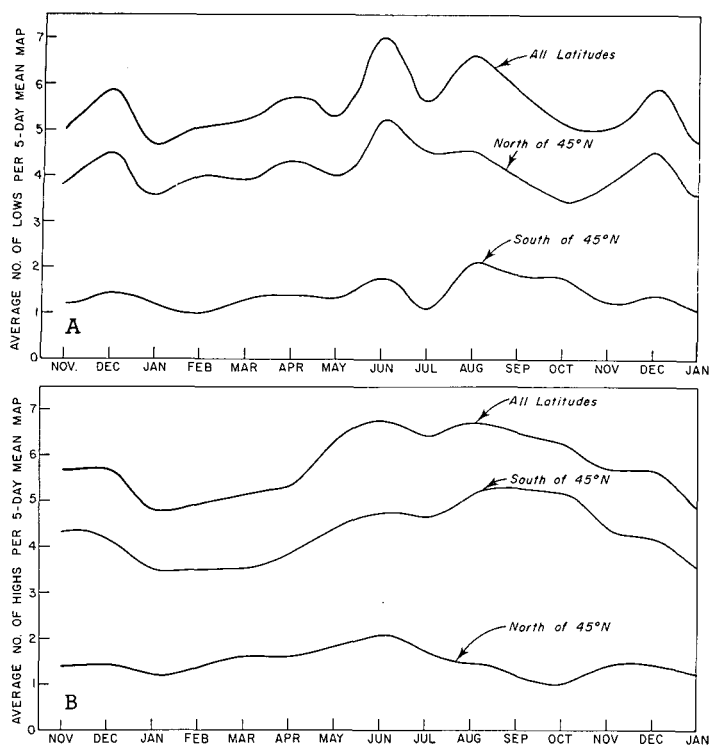


FIGURE 21.—Variation in average number of centers per 5-day-mean circulation at 700 mb. by months, in the latitudinal sectors indicated, for (A) Lows and (B) Highs for the period 1947-58.

by Klein [4] for daily sea level Lows for a much earlier period of 20 years, except for the absence of maxima at the very high latitudes.

It may also be of some interest to consider the monthly variation of the number of Lows throughout the hemisphere per 5-day mean map (fig. 21A). For all latitudes, Lows average about 5.6 per 5-day period, with a minimum of 4.7 in January and a maximum of 7.0 in June. June's maximum is due principally to high-latitude centers, while the second greatest frequency at all latitudes in August, 6.6 Lows per 5-day map, is due in part to the greatest number of low-latitude centers during the month. December's third highest frequency of 5.9 Lows per 5-day map is due in part to a marked increase at the very high latitudes (65° - 75° N.).

HIGHS

Mean Highs at 700 mb. are most frequent between 20° and 25° N., as shown in figure 18 for all months combined. About 75 percent of all Highs occur south of 45° N. and about 50 percent between 20° and 35° N. North and south of 20° to 25° N. there is a rapid decrease in frequency with a minimum frequency at 45° - 50° N., and again at the very highest latitudes.

A seasonal breakdown of latitudinal variations (fig. 19) shows that high-latitude Highs are most frequent in spring at 50° - 55° N. and in summer at 60° - 65° N. At

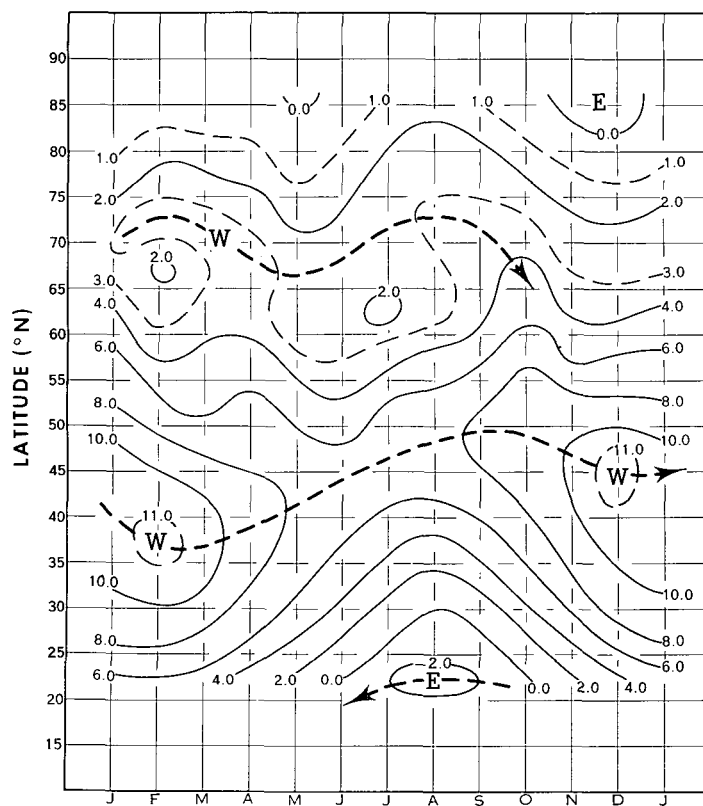


FIGURE 22.—Variation of mean zonal wind speed (meters per second), by months, at 700 mb. from 1947 to 1958, averaged by 5° latitude zones. The dashed curves are axes of maximum speed, with maximum westerlies labeled W, and easterlies E.

low latitudes figure 19 reveals the high frequencies of summer and fall Highs as well as the strong rising trend of subtropical Highs (both in frequency and latitude) from winter to summer.

A monthly stratification of latitudinal variations of Highs (fig. 20B) shows that, although most Highs occur between 20° and 25° N. on the yearly average, the zones of maximum frequency in individual months are more variable than for Lows. In only five months are the High maxima in the same zone as the yearly maximum, in contrast to nine months for Lows. The maximum frequencies of Highs occur at the lowest latitudes of the year from December to April. The belt of subtropical Highs subsequently progresses northward, increasing in latitude to 30° - 35° N. in July and August, receding southward thereafter. Highs also exhibit secondary frequency maxima of varying magnitudes in each individual month, with the strongest from April to June at 50° - 55° N., and others of lesser magnitude in March at 60° - 65° N. and in July at 65° - 70° N.

It may also be useful to consider the monthly variation of Highs throughout the hemisphere per 5-day-mean map (fig. 21B). For all latitudes mean Highs average 5.9 centers per 5-day-mean map, with the fewest in January

(averaging 4.8) and the most in June and August (averaging 6.7). June's maximum is due principally to high-latitude Highs, which reach the greatest frequency of any month north of 45°N . The maximum in August is due in large part to the high frequency of subtropical centers, together with relatively frequent occurrences north of 45°N . In September and October, which have the most frequent Highs south of 45°N ., high-latitude occurrences are at a minimum, with October having the least blocking of any time of the year.

6. MEAN ZONAL CIRCULATION

The time-latitude variation of mean zonal geostrophic wind speed at 700 mb. for the Northern Hemisphere, derived from the 1947-58 average monthly circulations in [3], is shown in figure 22. A comparison with the monthly variation of centers (fig. 20) reveals that the subtropical High maxima occur south of the wind maxima (jet axis) in a zone of average anticyclonic shear, as daily surface Highs do (see [4]). Highs are farthest north in July and August as is the jet axis. However, the Highs retreat southward in the fall whereas the jet axis remains close to the summer location throughout that season.

The high-latitude jet axis at 700 mb. from February to August (fig. 22) is not so clearly related to the secondary maxima of blocking Highs. On the contrary, the most frequent blocking occurs at 50° - 55°N . which is in a zone of cyclonic shear north of the mid-latitude jet. In addition, there is no high-latitude jet axis in the fall despite a secondary maximum of blocks which is admittedly weak. Of course the explanation is that blocks are far less fre-

quent than subtropical centers, in the ratio of about 1:3, and are usually less intense as well.

Lows are observed primarily between 55° and 60°N ., a zone of cyclonic shear. At low latitudes increased cyclonic activity during summer and fall is reflected in reduced subtropical westerlies and the onset of easterly winds at 700 mb. (fig. 22).

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